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IRRIGATION POTENTIAL OF INUAKPA IN ODUKPANI LOCAL GOVERNMENT OF CROSS RIVER USING KOSTIAKOV MODEL

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ABSTRACT

Infiltration measurements were carried out using cylindrical infiltrometer with height and diameter of 15cm and 5cm respectively. Sixteen infiltration runs were carried out in a composite grid (30m x 30m) in Inuakpa, Odukpani Local Government Area of Cross River State to test the efficiency of Kostiakov's model, measure infiltration rate and relate same to some soil physical properties. Mean infiltration rate of 9.01 $cmhr^{-1}$ was obtained at the end of the runs. The soil textural class was loamy sand with particle size distribution indicating mean values of 82.4, 7.2 and 10.4 % for sand, silt and clay respectively. The bulk density, particle density and total porosity had mean values of 1.35 Mgm^{-3}, 2.48 Mgm^{-3} and 44.86 % while their coefficients of correlation with infiltration rate where 0.58, 0.48 and 0.69 respectively. There were also linear and positive relationships between infiltration rate and sand and silt contents with coefficients of correlation of 0.92^{**} and 0.55^{*} ($p \leq 0.05$) respectively while clay content was not specifically linear or positive. Kostiakov infiltration model fitted well in evaluating infiltration parameters for sustained agricultural production. The soil infiltration rate, physical and chemical properties studied placed the soil in class 2 - irrigable. Mulching with plant residues, cover cropping, the use of restorative crops and zero tillage should be practiced in the area as soil management strategies.

INTRODUCTION

Irrigation is the artificial application of water to the land for improved and sustained crop growth. It is practiced where the amount of rainfall is either not enough to sustain plant growth or where the farmer intends to practice all year round crop production to meet up with demands from the increasing population in the area. According to Musa (1997), about 39 % of land mass (5,808660 ha) in the world is potentially suitable for agriculture and out of this, between 4.0 and 4.5 million hectares is judged suitable for irrigated agriculture but only 1.1 million hectare can be supported fully by the available water resources, the remaining 3.4 million hectare is being used as fadama. In Nigeria, far less than a million hectare is currently irrigated (NINCID, 2014).

The United States Bureau of Reclamation (USBR) (1953) recommended the following soil conditions for profitable and sustained irrigation agriculture: a reasonably high available soil water capacity, readily permeable soil, slow enough infiltration rate, sufficient depth, low amounts of injurious elements with adequate supply of plant nutrients and a favourable cation exchange capacity.

The most significant properties for assessing an irrigable soil for agriculture are those that determine the entry of water into the soil and its movement and retention in soil profiles (Esu, 1986), hence the necessity of infiltration rate in this research. According to Esu (1986), if the infiltration rate is between 0.1 and 0.2 cm/hr, surface waste may be excessive and ponding may bring about reduced yields and values lower than 0.1 cm/hr may consider the soils non-arable (except for rice) while optimum infiltration rate for gravity irrigation is between 0.7 and 3.5 cm/hr.

Evaluation of soil infiltration characteristics, and especially the final steady infiltration rate, is necessary for increased irrigation water use efficiency, the design of irrigation systems, decreased soil and water losses which are important factors in sustainable agriculture (Haghighi *et al.,* 2010). The determination of the final infiltration rate is time consuming, hence the adoption of the Kostiakov (1932) model in the estimation of infiltration rate. The predictive ability of the Kostiakov model for the final infiltration rate takes a longer time to obtain a steady infiltration rate, especially in soils with low initial soil moisture content (Navar and Synnott, 2000).

Infiltration is one of the important hydrologic processes in agriculture and urban drainage design and accurate measurement is essential as it plays a fundamental role in surface and subsurface soil hydrology as well as in irrigation and engineering practices. Over the last five decades, several studies have focused on infiltration into layered soils. It is found that the less permeable layers govern the infiltration process regardless of whether these layers lie above or below the more permeable layers (Hanks and Bouma, 1962; Childs, 1969).

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Irrigation increases the hectarage of arable lands that had been affected by either salt or dryness and also ensures successful harvesting during periods of dry spell. Year round crop cultivation can be practiced if irrigated farming is optimally practiced. If soils are not properly evaluated for their irrigation potential, irrigation can result in water logging, fungal diseases in crops and increase in the salinity of the soil to a point where crops are damaged and productivity is reduced. With rapidly increasing population, the need to put more rural and suburban lands under small scale irrigation to produce more food cannot be over emphasized.

Odukpani LGA has a tropical climate with average rainfall amount over 2000 mm/annum. The high rainfall should not necessitate the practice of irrigation, but dry season that lasts between December and early April gives famers great concern in the growth of crops. Farmers make more profit when they engage in off-season cultivation of crops because supply is low and the crop is more expensive and scarce. It's in this vein that farmers in the area especially those involved in the growth of vegetables and arable crops such as maize, telfaria, water leaf, amaranthus, water melon, cucumber, etc practice irrigation to meet up with the requirement of crops for dry season farming, so as to feed its increasing dependants in the suburban area.

The objectives of this study are;

i) To characterize the soil
ii) To determine the infiltration characteristics of the soil and test the efficiency of the Kostiakov (1932) model.
iii) To determine the relationship between infiltration rate and some soil physical properties.

MATERIALS AND METHODS

Location of Study

The study was located at the Odukpani Qua Clan area in Odukpani LGA (Fig1). The area is located between latitudes $4^0$05' and $6^0$29' N and Longitudes $8^0$15' and 9^0 30' E in Cross River State, Southeastern Nigeria.

The area is characterized by a humid tropical climate with distinctive wet and dry seasons. The rainy season spans between April and November with double peaks in June to July and September to October, while dry seasons range between December and April with the driest and hottest period being in March. Within the dry period, harmattan weather condition occurs between December and February which is characterized by a dry dusty wind with very low night temperatures. Annual rainfall is between 2,000 mm and 4,300 mm, and average daily temperature ranges from 22 to 25 ^{0}C (NIMET, 2012).

Odukpani is characterized by coastal plain sands belonging to tertiary and alluvial deposits. The geology of the area consists of old sedimentary materials as well as some granitic intrusions exposed at the surface. The soils are shallow and erodible on steeper slopes with spots of quartz, gneiss and speckles of muscovite commonly observed on eroded hillsides.

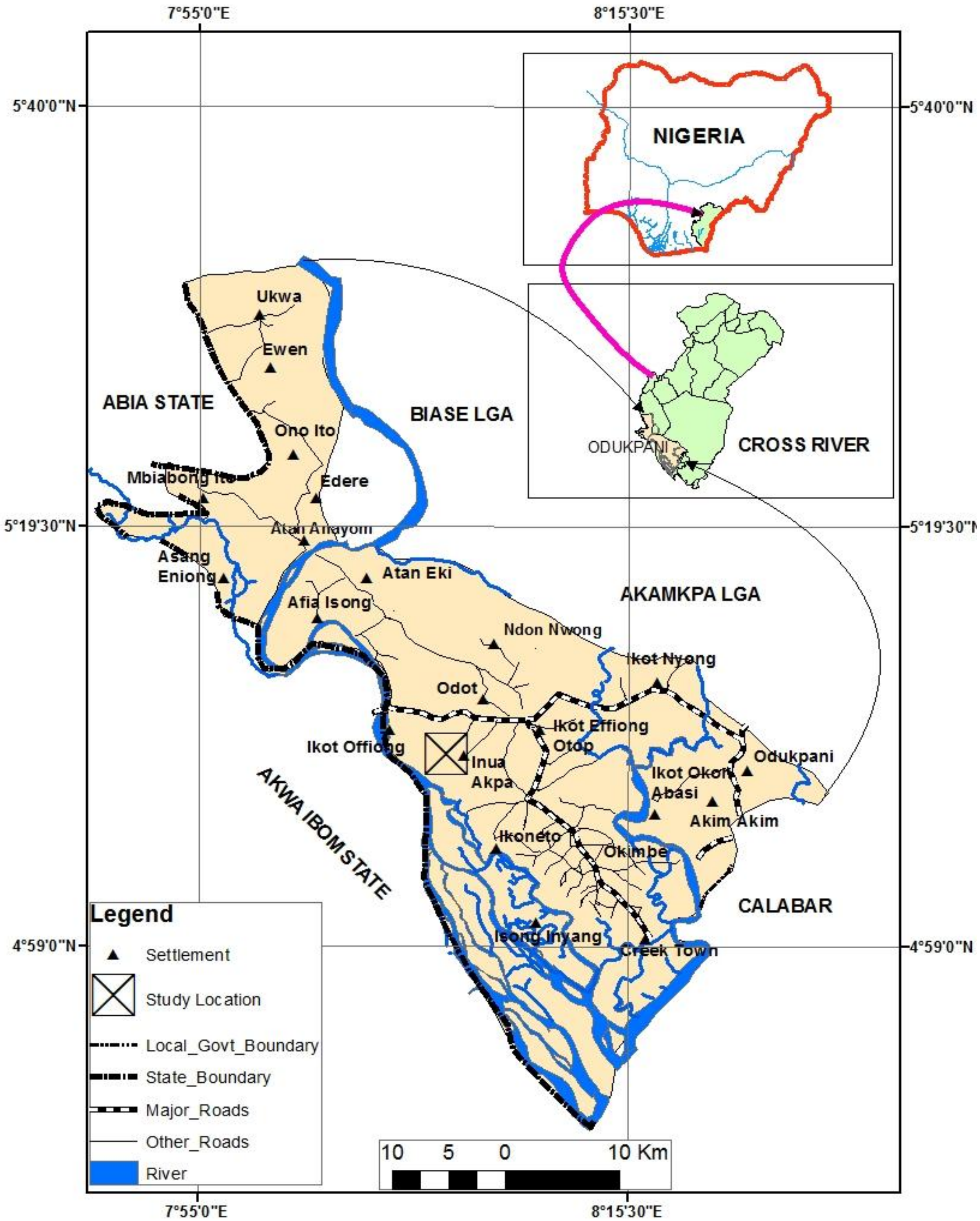


Figure 1: Map of Odukpani LGA showing the study area

The study area is about 100 m above sea level (ASL) in the south and 170 m ASL in the south-west, and is characterized by a complex network of rivers, streams and rivulets. The vegetation in the area is characterized by a flora that forms a closed canopy and scattered emergent trees reaching the height of 4 - 5 m. Most of the rainforest vegetation has been cut down for the cultivation of crops, mostly vegetable and arable crops as well as for non-agricultural activities. Secondary forest is now common.

Field Methods

In the location of study, a composite grid measuring 30m x 30m was lined out using a measuring tape, a rope and some pegs. Sixteen observation points were marked out, each measuring 10 m x 10 m (Fig 2). At each transverse of the grid, infiltration runs were conducted, observations made and undisturbed core samples taken to the laboratory for the determination of bulk density (Blake, 1965). Samples for Particle density, particle size distribution and total porosity were also obtained from the field. Composite samples were also collected from all the observation points, bulked and sub sampled for chemical analysis.

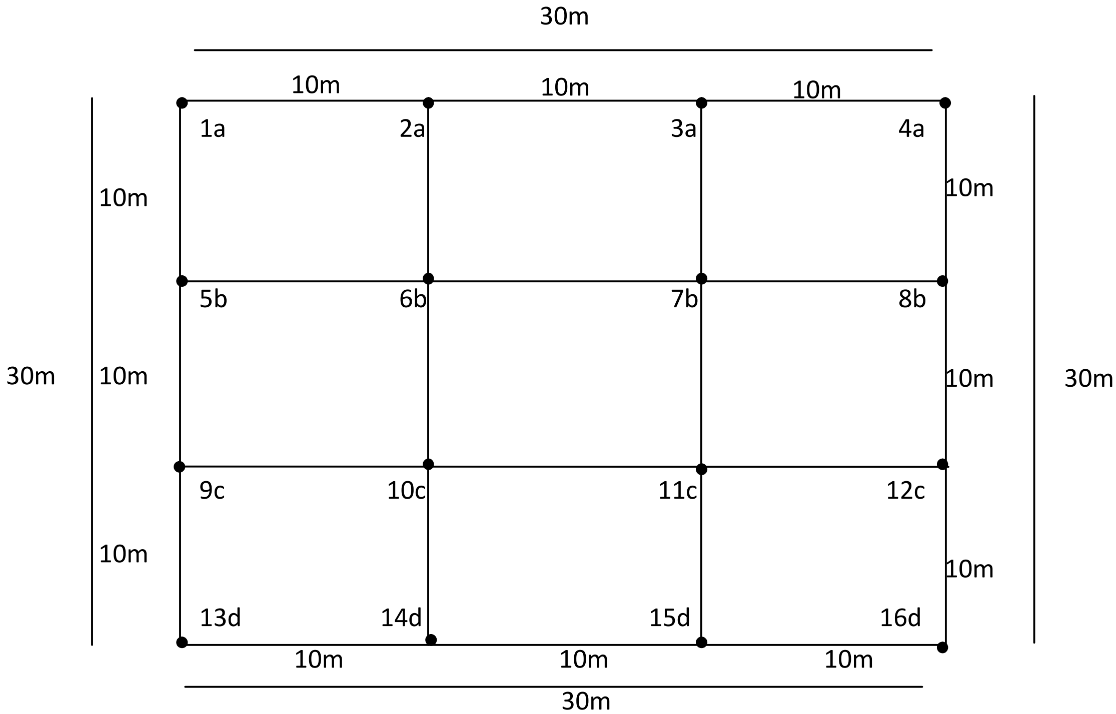


Figure 2: A composite grid showing the experimental test points (1a-16d) for infiltration runs and soil sampling.

Measurement of Infiltration rates
The infiltration rate was determined with a cylindrical infiltrometer of height 15 cm placed at each point of observation. It was then driven half way (7.5 cm) into the soil with minimum disturbance and its base mulched to reduce lateral flow, particle dislodgement and disturbance. Water was filled to the brim of the cylinder and the time (t) was taken for the water to infiltrate into the soil up to 2 cm depth. This marked a constant hydraulic head throughout the runs.

Laboratory Studies
The particle density was determined as described by Tel and Hagarty. (1984) while the total porosity was calculated from the relation:

{1 - (Db/Dp)}*100

Where Db is the dry bulk density and Dp is the particle density. Particle size analysis was carried out by the Bouyoucos Hydrometer method using sodium hexametaphophate (Calgon) as the dispersing agent (Gee and Bauder, 1986). The percentage sand, silt and clay were then used to determine the soil textural class using a soil textural triangle.

Soil pH (H_2O) was determined potentiometrically in a 1:2.5 soil:water suspension. Organic C was determined by the Walkley and Black wet oxidation method (IITA, 1979). The total nitrogen was determined by the macro Kjeldahl digestion method (Udo *et al.,* 2009). 'Available P was determined by the Bray No. 1 method as described by Murphy and Riley (1962). Exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ were extracted using 1N NH_4OAc (pH 7.0). Exchangeable Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrophotometry (Thomas, 1982) while Na^+ and K^+ were determined by flame photometry. Effective cation exchange capacity was determined by the summation of exchangeable bases and exchangeable acidity as described in IITA (1979).

RESULTS AND DISCUSSION

Physical and chemical characteristics of the soil
The mean infiltration rate from the 16 observation points at Inuakpa study area was 9.01 $cmhr^{-1}$ with a range of 0 – 20.7 $cmhr^{-1}$ (Table 1). This rate is marginally suitable for irrigation but rapid and indicates no limitation as mean value was greater than 5.0 $cmhr^{-1}$ (Lal, 1994). According to Landon (1991), when basic infiltration rate is within the range of 6.5 – 12.5 $cmhr^{-1}$, suitability for surface irrigation is marginal and small basins are required for the irrigation. The moderate rate of infiltration could be due to high sand content (82.4%) in the coastal plain soils and low organic matter content. High soil organic matter content ensures good soil aggregate formation and favourable water movement.

The mean bulk density of the soils was 1.35 Mgm^{-3} (Table 1), such values are not likely to restrict air and water movement in the soil and are within the range of 1.20 – 1.64 Mg/m^3 reported by Asadu *et al*. (1990) for some yam growing soils of southeastern Nigeria. The mean value of particle density was 2.48 Mgm^{-3} (Table 1). This value is within the acceptable limit of 2.65 Mgm^{-3} for mineral soils. A mean value of 44.9 % and range of 36 – 72% (Table 1) for total porosity was within the acceptable range of 30 – 70% reported by Landon (1991) for mineral soils. The mean values of the sand, silt and clay contents were 82.4, 7.2 and 10.4% respectively (Table 1).

The chemical properties of the top soil are summarized in Table 2. The strongly acid soils had a mean value of 5.0 for soil pH (H_2O), this value is probably due to the leaching of the soils basic cations as a result of the sandy textures and high rainfall amount in the area. Organic carbon and total nitrogen levels were low (Holland *et al.,* 1989) with mean values of 1.1% and 0.09 % respectively. This could be attributed to low accumulation of litter at the top soil or high rate of mineralization and subsequent leaching due mainly to the tropical climatic condition. The Available P in the soil was high and had a mean value of 72.25 $mgkg^{-1}$. The effective cation exchange capacity was low (Holland *et al.,* 1989) with a mean value of 3.86 $cmolkg^{-1}$. This value was a reflection of the low exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) in the soils. Mean value of 83.9 % was obtained for base saturation. Base saturation is high (Holland *et al.,*1989) and indicates the availability of exchangeable cations. According to Ekpete (1972) and Peter (2013); soils of Eastern Nigeria are deficient in potassium while Akpan-Idiok *et al.* (2012) obtained low values of exchangeable cations in the coastal plain soils of Calabar. The general fertility status of the soil was rated low mainly due to the leaching of basic cations and other nutrients due, mainly to the high rainfall and sandy textures in the area.

Upon comparing the physical and chemical properties (Tables 1 and 2) of the soils to the provisions of USBR (1953) (Table 3), the soils are classified as class 2 – irrigable.

Infiltration Characteristics and prediction of infiltration rate using Kostiakov (1932)

A plot of the infiltration rate against time is shown in Figure 3. Kostiakov's (1932) infiltration equation of $i = \alpha t^n$ was transformed into logarithmic expression of $\log i = n\log t + \log \alpha$.

Where a plot of log i versus log t gave a straight line (Fig 4), with slope "n" = 1.87. The constant "n" is an index of soil structural stability at which the infiltration decreases as a result of the breakdown of soil structural units (Babalola, 1977; Mukhtar *et al*., 2013).

The intercept on log i axis gave the value of α as – 0.4, indicating a low constant. This constant is a measure of the structural condition of the soil. Babalola (1977) and Mukhtar *et al*. (2013) opined that if a soil has large earthworm or termite holes, the α-value would be very high. The low value indicates low activities of earthworms and termites probably due to the acidic nature of the soils. The discrepancy between the theoretical and calculated values may be explained by possible entrapment of air in the soil during infiltration runs (Ghosh, 1982).

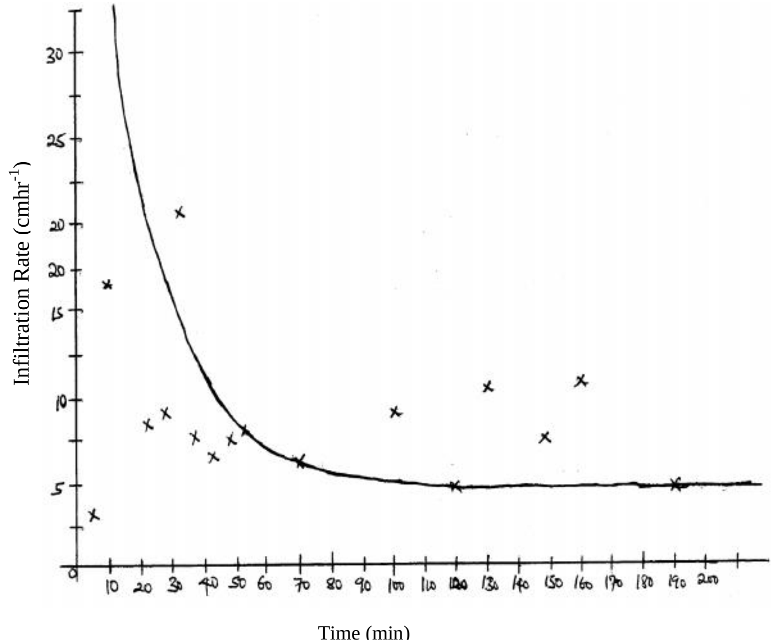


Fig 3: Graph of Infiltration Rate versus Time

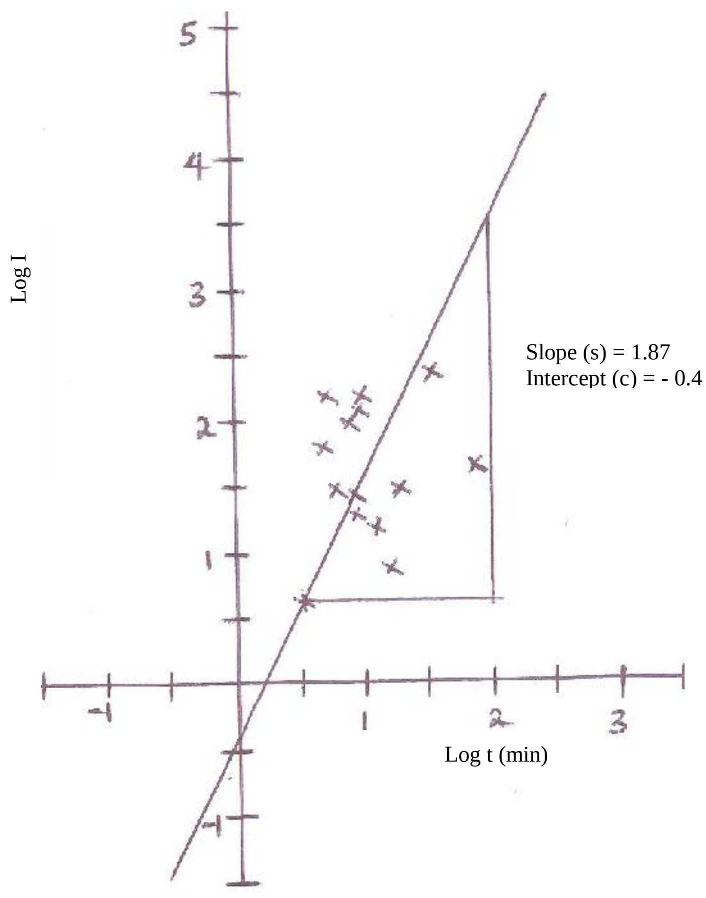


Fig 4: Graph of Log I versus Log t

Correlation matrix between infiltration characteristics and soil physical properties

The coefficient of correlation between the mean infiltration rate and sand, silt and clay contents were 0.92^{**}, 0.55^{*} and 0.53^{*} respectively. Figures 5 and 6 show linear relationships with positive slopes for sand and silt while Figure 7 shows non linear curve for clay when related with infiltration rate. This could be due to spatial variability of soil properties (Amalu and Antigha, 1999; Xingyuan 2007; USDA, 2012). The high correlation co-efficient which approached one for sand indicates high infiltration rates in sand dominated soils while the low coefficient of correlation in clay indicates low infiltration rates. This affirms texture as the most predominant characteristic of the soil affecting infiltration rate (Saxton *et al.,* 1986) and inconsistent with the results obtained by Osuji *et al*., (2010).

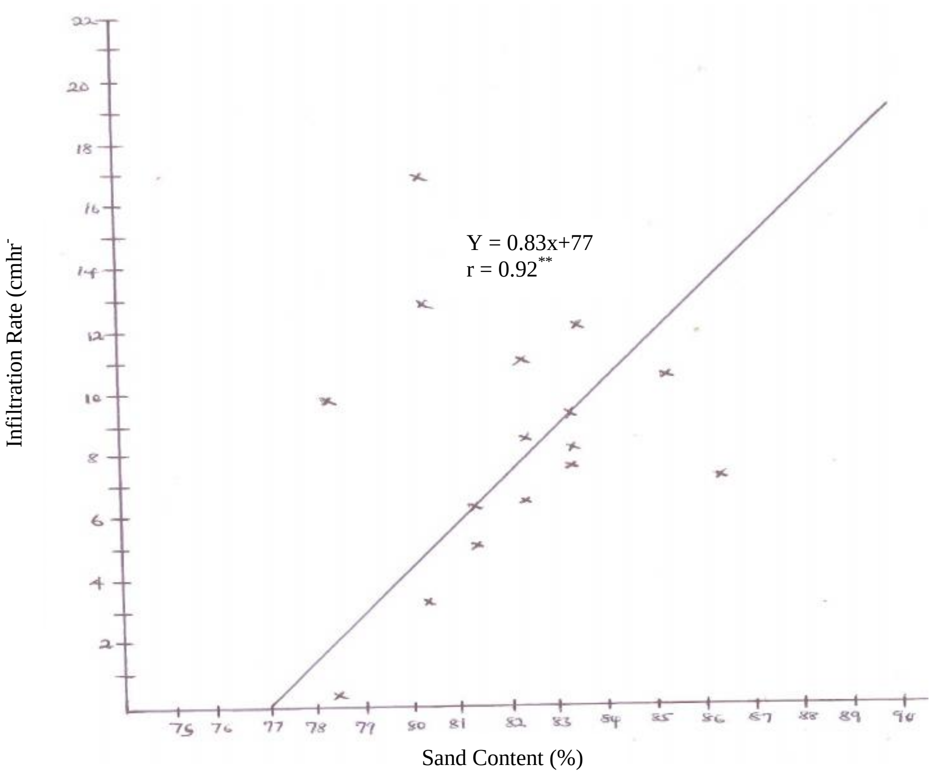


Fig 5: Graph of Infiltration Rate versus Sand Content

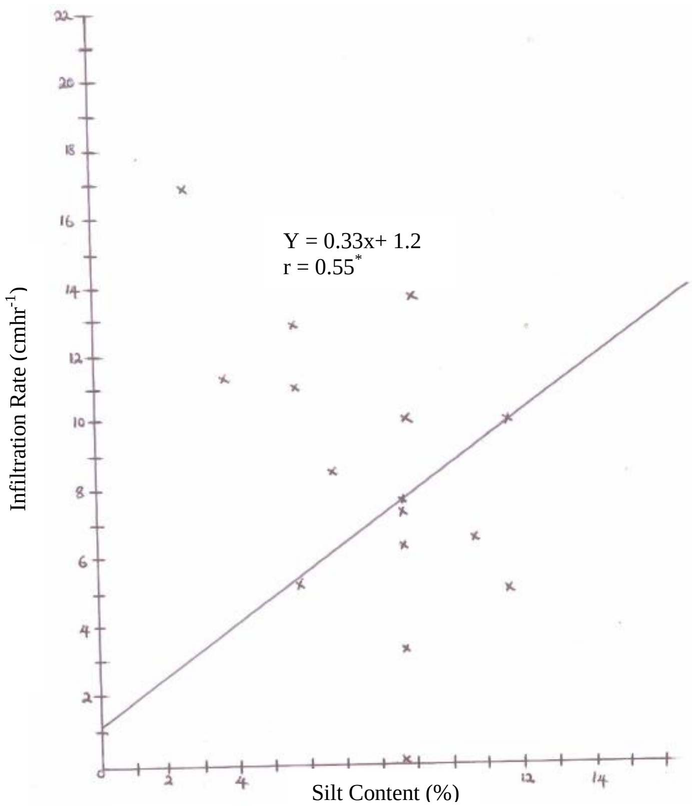


Fig 6: Graph of Infiltration Rate versus Silt Content

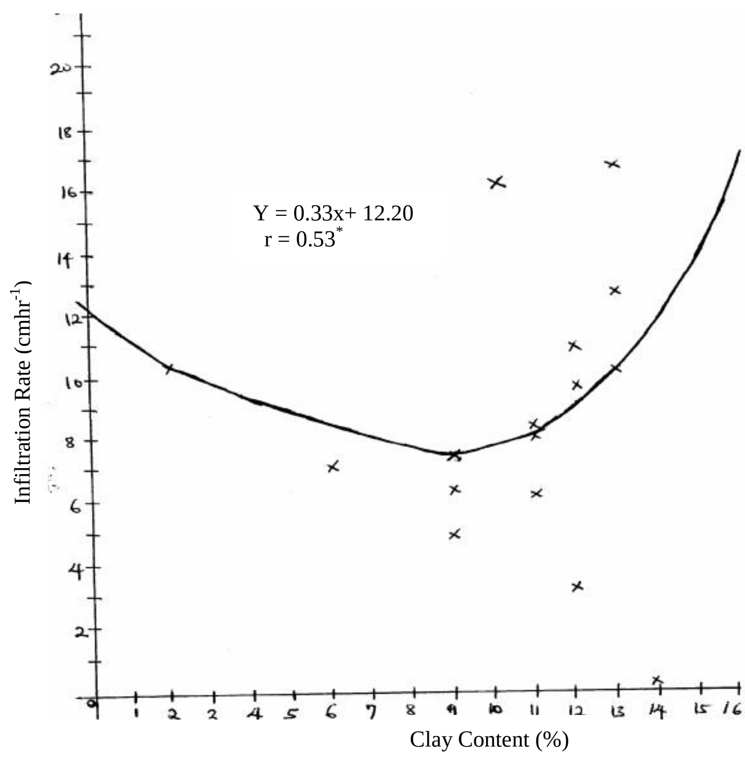
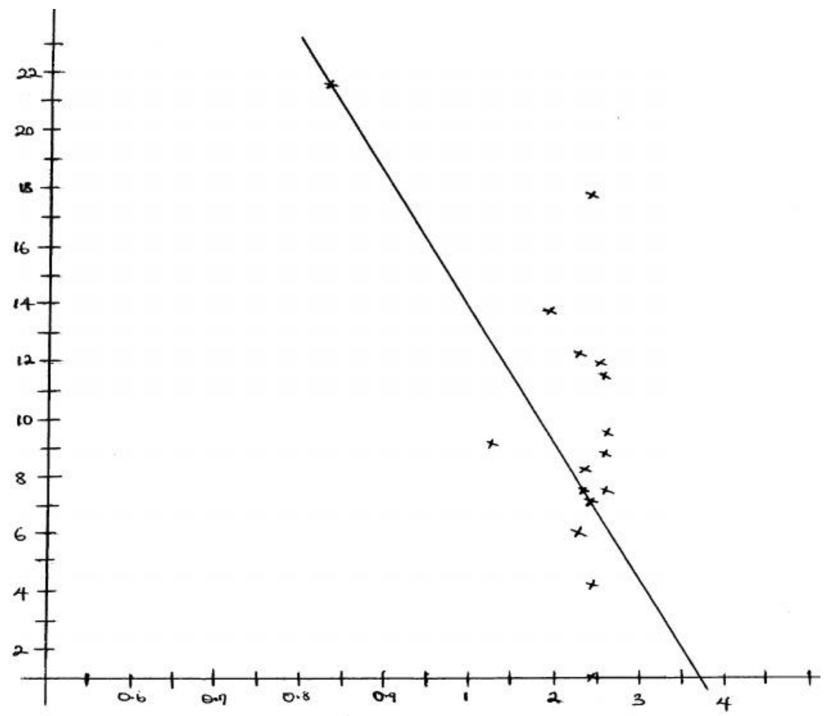


Fig 7: Graph of Infiltration Rate versus Clay Content

As bulk density increased, there was a tendency for infiltration rate to reduce (Fig 8), hence the low coefficient of correlation value of 0.58. Thompson and Troeh (1973) observed that root growth and water penetration are likely to be slowed down significantly by soils having bulk densities in the range of 1.5 – 1.6 Mg/m^3. Particle density seems not to be directly correlated with infiltration rate as a coefficient of correlation of 0.48 was obtained.

The relationship between the infiltration rate and total porosity was also established with coefficient of correlation of 0.69 (Fig. 9). The range of porosity of 36 – 72% (Table 1) reflects the relatively high correlation coefficient indicating high infiltration rate in porous soils.

Infiltration Rate ($cmhr^{-1}$)



Bulk Density (Mgm^{-3})

Fig 8: Graph of Infiltration Rate versus Bulk Density

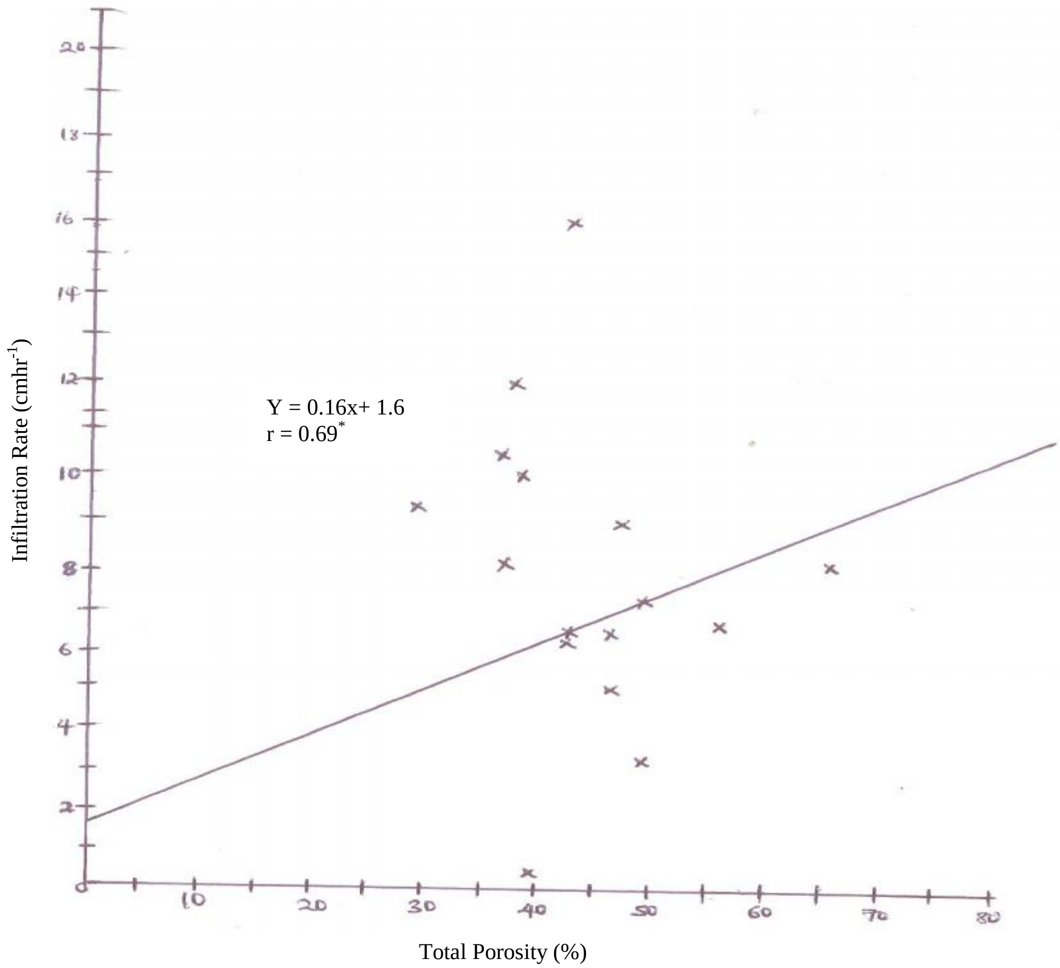


Fig 9: Graph of Infiltration Rate versus Total Porosity

TABLE 1: Infiltration Rate and other Physical Properties of the Soils.

Observation point	Cumulative time	Infiltration Rate	Bulk Density	Particle Density	Total Porosity	Sand	Silt	Clay	Textural Class
	Min.	**(cmhr^{-1})**	← **Mgm^{-3}** →		←	**%**	→		
1a	0	0	1.45	2.40	39	78.3	7.7	14.0	Loamy Sand
2a	4	3.4	1.45	2.59	49	80.3	7.7	12.0	Loamy Sand
3a	9	16.8	1.45	2.51	42	84.3	2.7	13.0	Loamy Sand
4a	16	12.9	1.42	2.27	37	81.3	5.7	13.0	Loamy Sand
5b	21	8.5	1.54	2.25	39	82.3	6.7	11.0	Loamy Sand
6b	27	9.4	1.35	2.55	47	83.3	3.7	13.0	Loamy Sand
7b	32	20.7	0.68	2.47	72	85.3	5.7	9.0	Loamy Sand
8b	37	7.3	1.31	2.67	49	86.3	7.7	6.0	Loamy Sand
9c	42	6.6	1.41	2.61	46	82.3	8.7	9.0	Loamy Sand
10c	48	7.6	1.46	2.50	42	83.3	7.7	9.0	Loamy Sand
11c	52	8.2	0.92	2.63	65	83.3	5.7	11.0	Loamy Sand
12c	70	6.3	1.42	2.47	42	81.3	7.7	11.0	Loamy Sand
13d	100	9.7	1.46	2.07	29	78.3	9.7	12.0	Loamy Sand
14d	130	10.6	1.52	2.47	38	85.3	12.7	2.0	Loamy Sand
15d	160	11.1	1.50	2.36	36	82.3	5.7	12.0	Loamy Sand
16d	190	5.1	1.23	2.28	46	81.3	9.7	9.0	Loamy Sand
Total	**848**	**144.2**	**21.58**	**39.69**	**718**	**1313.8**	**115.7**	**166.0**	
Means	**53**	**9.01**	**1.35**	**2.48**	**44.86**	**82.4**	**7.2**	**10.4**	
Correlation			**0.58**	**0.48**	**0.69**	**0.92**	**0.55**	**0.53**	

TABLE 2: Chemical Properties of the Soils

Properties	Values
pH	5.00
Organic carbon (%)	1.09
Total Nitrogen (%)	0.09
Available Phosphorous ($mgkg^{-1}$)	72.25
Ca^{++} ($cmolkg^{-1}$)	2.30
Mg^{++} ($cmolkg^{-1}$)	0.80
K^{+} ($cmolkg^{-1}$)	0.08
Na^{+} ($cmolkg^{-1}$)	0.06
H^{+} ($cmolkg^{-1}$)	0.11
Al^{+++}($cmolkg^{-1}$)	0.51
ECEC ($cmolkg^{-1}$)	3.86
Base saturation (%)	83.94

TABLE 3: Modified USBR Land Suitability class specification for gravity irrigation (USBR 1953)

Land characteristic	Class 2: irrigable
surface texture (0-30cm)	Fine sand to loamy fine sand
Sub surface soil texture (30-80cm)	fine sandy loam to fine sandy clay loam
Effective rooting depth	75- 100 cm
Infiltration rate after 4 hours	5.0 – 12.0 $cmhr^{-1}$
Soil fertility status	Medium to low
Exchangeable sodium percentage (ESP)	15 -20 %
Permissible gravel	15 -50%
Rockiness (small out crops)	0 -2% of surface
Topography (slope)	2 - 4 %
Vegetative cover	Secondary forest that has been influenced by anthropogenic activity
Drainage/perched water table	100 -150cm
Drainage	No immediate farm drainage/ profile well drained.

SOURCE: USBR, 1953

CONCLUSION

This study was carried out in Inuakpa in Odukpani to assess the irrigation potential of the area using Kostiakov infiltration model (1932). The infiltration rate, selected physical and chemical properties of the soil places the soils in class II of irrigable soils. It was observed that infiltration rate is greatly influenced by bulk density, total porosity and soil textural classes and to a lesser extent by particle density. The mean infiltration value indicates moderate infiltration rate and predicts a favourable irrigation potential if soil management procedures that enhance soil aggregation are put in place. Mulching with plant residues, cover cropping, the use of restorative crops and zero tillage should be encouraged in the area. These practices will encourage the buildup of organic substances, encourage soil aggregate formation and subsequently reduce erosion.

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